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SULPHUR AS A FACTOR IN SOIL FERTILITY

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY **289**

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Introduction

Although sulphur was recognized as an essential element in plant nutrition as early as the middle of the nineteenth century, the use of sulphur and sulphur compounds as fertilizers has never become general. Analyses for sulphur in soils have generally been low, yet when compared with the sulphur in the ash of plants, the amount present in the soil seemed sufficient for all the needs of the crop. The use of gypsum as a fertilizer, however, was quite extensive for a time, following the discovery of its beneficial effect on plants. BROWNE (13) credits this discovery to a clergyman in Germany in 1768. From there it spread to France and Great Britain, and was brought to the United States by BENJAMIN FRANKLIN, who used it on his farm near Philadelphia. For a time gypsum was extensively used as a fertilizer both in Europe and the United States and gave remarkable results. GRIFFITHS (25) reports experiments by SCHUBERT in Germany, and CROCKER (15) refers to the experiments of Judge PETERS, JOHN BINNS, and EDMUND RUFFIN in the United States. All these men obtained remarkable results with gypsum on legumes.

The use of gypsum alone, however, soon failed to increase crop yields, and investigators seeking for an explanation came to the conclusion that the gypsum acts chemically on the phosphorus or potassium compounds in the soil and liberates either phosphorus or potassium or both. This view is presented by GRIFFITHS (25), VOORHEES (72), and HOPKINS (32). BROWNE (13) and BRUCKNER (14) consider the beneficial effect of gypsum due, in part at least, to the nutrient effect of the sulphur; while VENDELMANS (70) and HILGARD (31) mention its beneficial effects, particularly on the legumes, without giving any explanation.

In most fertilizer experiments sulphur has been added, together with phosphorus, in acid phosphate or basic slag, or with the potassium in potassium sulphate or kainit. When beneficial results have been obtained, the investigators have invariably ignored the possible effects of the sulphur. This may lead to erroneous conclusions, as was pointed out by LIEBIG (37) in 1855. He said that the sulphur or the calcium in the acid phosphate, or both, might have had a beneficial effect on the turnips in the Rothamsted experiments, as well as the phosphorus.

HOPKINS, MOSIER, PETTIT, and READHIMER (33) found that kainit increased the yields of corn, wheat, and oats on the waste hill land of Johnson County, Illinois, when used with bonemeal, ground limestone, and crop residues, over similarly treated plots without kainit. On the plots receiving no kainit, as well as on those receiving the kainit, cowpeas were grown once every three years and turned under as part of the crop residues. STEWART (66) compared potassium chloride and potassium sulphate as fertilizers for apple orchards in Pennsylvania. He found no appreciable difference in the effect of these salts. SMITH (65) found a greater yield of oat straw for potassium sulphate than potassium chloride in pots containing Hagerstown silt loam.

BROOKS (8) compared the effects of potassium sulphate and potassium chloride on alfalfa in field experiments at the Massachusetts Agricultural Experiment Station. Both plots received 600 pounds of bonemeal per annum, and both received 2 tons per acre of hydrated lime before planting the alfalfa. Both Grimm alfalfa and common alfalfa were used. Potassium sulphate gave increased yields of 0.50 tons of Grimm alfalfa and 0.75 tons of common alfalfa over potassium chloride. In every case the alfalfa on the plots receiving potassium sulphate was a darker green than on the plots receiving potassium chloride. The same difference in color was reported for the same treatment on other crops. BROOKS (9) also made a comparison of different phosphate fertilizers. He found that acid phosphate and dissolved boneblack, which contain sulphur, gave greater increases in crop yields than raw bonemeal and rock phosphate, which contain little or no sulphur. A more rapid early growth of both tops and roots and earlier maturity were observed on the plots receiving the dissolved boneblack and acid phosphate than on the plots receiving raw bonemeal and rock phosphate.

The use of flowers of sulphur as a fertilizer was observed to have an influence aside from its effect in destroying the fungi which cause plant diseases. MARES (50) noticed a much greater vigor in vines that had been sulphured than in those which had not. He found that the sulphur was oxidized to sulphuric acid in the soil, and he thought that the sulphuric acid acted on the insoluble compounds containing potassium and made the potassium soluble. DEMOLON (16) found that heating the soil prevented the oxidation, and so he concluded that oxidation was caused by microorganisms. PFEIFFER and BLANCK (56) obtained no increased yields of oats for the use of flowers of sulphur in field experiments. FEILITZEN (21) in Europe, and SHERBAKOFF (64) in the United States both obtained increased yields of potatoes from the use of flowers of sulphur.

BOULLANGER and DUGARDIN (3) found flowers of sulphur increased ammonification but decreased nitrification. The harmful effect on the nitrifying bacteria was probably due to the acidity, as LINT (38) found that the oxidation of sulphur in the soil increased the acidity very much. FRED and HART (23) report an increase in ammonification from the use of gypsum in peptone solutions, and WARINGTON (73) obtained an increase in nitrification when gypsum was applied to solutions of urea. GREAVES, CARTER, and GOLDTHORPE (24) studied the influence of calcium sulphate on production of nitrates and found it caused a great increase in all concentrations used. The increase was very high for the higher concentrations of calcium sulphate.

BRIOUX and GUERBET (7) found that flowers of sulphur increased availability of calcium and potassium in both calcareous and noncalcareous soils, but had no effect on phosphorus. LIPMAN and McLEAN (42) found that composting rock phosphate with sulphur increased the solubility of phosphorus. McLEAN (48) found an increase of solubility of phosphorus in the sulphur-rock phosphate compost when compost was inoculated. The presence of soluble phosphates and sulphates did not inhibit the action. LIPMAN, McLEAN, and LINT (43) found a great increase in acidity in the sulphur-floats mixture. LIPMAN and JOFFE (41) found no increased availability in phosphorus when acidity was increased by the addition of sulphuric acid. ELLETT and HARRIS (20) found greater availability of phosphorus in a manure-soil-floats-sulphur compost than in a soil-floats-sulphur compost. AMES and RICHMOND (2) found no increased availability of phosphorus in a compost to which calcium carbonate had been added. Acid conditions are necessary for the solution of the phosphorus. BROWN and GWINN (10) found an increased solubility of phosphorus in soil treated with sulphur as well as in composts. BROWN and WARNER (12) found no increased solubility of phosphorus in a manure-floats compost, but a great increase when flowers of sulphur were added to the compost.

The use of gypsum as a preservative of the nitrogen in manure has been investigated by HEINRICH (30), VIVIEN (71), NOLTE (53), and by AMES and RICHMOND (1). All these investigators report a saving of nitrogen from the use of gypsum on the manure.

Investigations on the effect of flowers of sulphur on the availability of potassium in greensands were conducted by McCALL and SMITH (45). They found an increase in the availability of potassium in composts of sulphur, greensands, and manure, but no increase in availability of potassium in composts of sulphur, greensands, and soil.

Reports of investigators who studied the influence of gypsum on the availability of potassium do not agree. McCOOL and MILLAR (46) found calcium sulphate applied to soil lowered the freezing point of the soil. No report was given as to the character of the compounds that lowered the freezing point. BRADLEY (4) found an increase in solubility of potassium but not of phosphorus in Oregon soils. BRIGGS and BREZEALE (6) found a decrease in solubility of potassium in California soils when gypsum was added, and the solubility of potassium decreased as the amount of gypsum used was increased. BREZEALE and BRIGGS (5) grew wheat in water cultures, using extracts from orthoclase minerals with and without gypsum. The gypsum did not increase the availability of the potassium to the wheat. MORSE and CURRY (52) treated feldspars with gypsum for ten weeks in water, filtered off the solution and analyzed for potassium. Only slightly more potassium was found than when no gypsum was used. MCMILLAR (49) treated five different soils with gypsum for three months and analyzed for soluble potassium. Gypsum was used at the rate of ten tons per acre and resulted in an increase in soluble potassium in every case. TRESSLER (69) found an increase in soluble potassium in some soils, but no increase in others when treated with gypsum. LIPMAN and GERICKE (39) obtained an increase of available potassium in greenhouse soil, a slight increase in adobe soil, and no increase in sand. FRAPS (22) grew plants in pots of soil treated with gypsum and analyzed the plants for potassium. He found no increase in potassium in plants grown on the gypsum-treated soil above that on the soil without gypsum. He reports no analyses of the soils used, however, so it is not known whether these soils were deficient in potassium or not. If the soil has sufficient potassium in an available form to supply all the plants' needs, there would not likely be any increased absorption even if the soil treatment dissolved some of the insoluble potassium compounds in the soil. On the other hand, in a soil deficient in potassium and sulphur, the application of gypsum or any other fertilizer containing sulphur would stimulate the growth of roots, and the increased size of the root system would make it possible for the plant to absorb more potassium. This increased absorption would take place regardless of any possible effects on the solubility of the potassium compounds in the soil.

The experiments of MCMILLAR (49), TRESSLER (69), and LIPMAN (39) indicate a greater solubility of potassium in some soils when treated with gypsum, but other soils show no effect, while BRIGGS and BREZEALE (6) report a decrease in solubility when gypsum was used. It seems, therefore, that the beneficial effects of gypsum can hardly be ascribed to its effect on the solubility of the potassium in the soil. It seems more likely that the soils that respond to the use of gypsum are deficient in some element that is supplied by the gypsum.

Recent studies of methods for the analysis of organic material for sulphur have shown that all the sulphur is not recovered in the ash when organic material is burned. HART and PETERSON (27, 28) found one hundred times as much SO_3 in the rice grain as in the ash of that grain, and forty times as much in the corn grain. Similar results were obtained with other grains, but the ratios were less in some cases. Onions, potatoes, crucifers, and legumes use large quantities of sulphur. Alfalfa removes twice as much sulphur as phosphorus from the soil. PETERSON (55) studied the sulphur compounds in plants and found proteins, volatile compounds, mustard oils, and sulphates. In ashing the plant material the sulphates remain, but at best part of the sulphur in other compounds is lost. Most soils are low in sulphur, which is present in the soil in the form of sulphates and organic matter. Sulphates are all soluble, and, like nitrates, they are not adsorbed to any great extent, and therefore are quickly leached out of the soil in the humid regions. The organic sulphur is insoluble but is readily oxidized to sulphates, so that it is gradually being lost unless taken up by the plant. LYON and BIZZELL (44) in their lysimeter studies at Cornell found that the loss of sulphur in the drainage from uncropped lysimeters was as great as the loss in drainage and in the crops from cropped soil. The oxidation of organic sulphur to sulphates seemed to continue at the same rate in cropped and uncropped soil, and that not taken up by plants was lost in the drainage.

Cultivation stimulates oxidation and consequently the loss of sulphur. SWANSON and MILLER (68) report a loss of 38.53 per cent of sulphur from the surface and 41.56 per cent from the subsoil of Kansas soils due to cropping. The surface soil of virgin land had 0.044 per cent sulphur, while adjoining cropped land had 0.027 per cent. The sulphur content of the subsoil was 0.062 per cent in the virgin land and 0.036 per cent in the cropped land. On the other hand, phosphorus was practically the same in the cropped as in the virgin land in both surface and subsoil. The cultivated soils had been cropped for thirty to forty years.

Lyon and Bizzell (44) found an increased loss of sulphur in the drainage when burnt lime was used, while MacIntire, Willis, and Holding (47) found the loss greater for calcium carbonate than for calcium oxide. It seems the carbonate favors bacterial action much more than the oxide.

Robinson (59, 60) analyzed a large number of soil samples from different parts of the United States for sulphur and phosphorus. Most of them were low, some extremely low, in both phosphorus and sulphur. Many of the samples were much lower in sulphur than phosphorus. Brown and Kellogg (11) analyzed samples of Iowa soils and found the sulphur content varied from 719 to 938 pounds per acre in the surface soil, while the phosphorus content varied from 1289 to 1538 pounds per acre. Shedd (62) analyzed samples of Kentucky soils and found the sulphur content in the surface soil varied from 213 to 1080 pounds per acre in virgin soil, and from 180 to 560 pounds per acre in cultivated soils. The phosphorus content in the surface soil ranged from 320 to 5860 pounds in virgin soil, and from 320 to 7240 pounds in cultivated soil.

Some sulphur is brought down from the air in rain water. The amount is probably greater during periods of heavy rainfall than when the precipitation is slight. Near cities, where a large amount of coal is burned, the amount is probably much greater than in country districts far from cities and railroads. The data, however, are too meager to form any definite conclusions. Hall (26) reports sulphur analyses of rain water at Rothamsted from 1881 to 1887 which give an annual average of seven pounds of sulphur in the rain water per acre per year. Analyses by Hart and Peterson (27) at the University of Wisconsin for part of a year led them to the conclusion that the amount in one year would be approximately the same as found at Rothamsted. Stewart (67) analyzed rain water at the University of Illinois and obtained as a seven-year average 45.1 pounds of sulphur per annum. All of these analyses are of rain water collected near cities. The water in the rain gauges is likely to be contaminated by dust and soot and by the droppings of birds which roost on the rain gauges.

Lawes and Gilbert (36) found, in their fertilizer experiments with red clover, that "the produce was considerably increased by the application of gypsum, and still more so by that of the sulphates of potash, soda, and magnesia, and superphosphate of lime." In four years the increased yield from the use of gypsum was 3.5 tons of dry hay, or an average of 0.9 ton per acre per year.

Hunt (35), at the Pennsylvania Agricultural Experiment Station, used gypsum in a rotation of corn, oats, wheat, and hay (timothy and clover). Gypsum was applied at the rate of 320 pounds per acre per rotation in two applications, 160 pounds to the corn and 160 pounds to the wheat. No other fertilizers were used, and no increases in yields were obtained from the use of gypsum. These experiments would be more valuable if the gypsum had been applied to the clover and other fertilizers had been used to remove the possibility of another limiting factor.

Miller (51) grew clover in pots containing Oregon soils. Applications of sulphur were made in the form of flowers of sulphur, sodium sulphate, and gypsum. Gypsum and sodium sulphate gave increased yields, but the flowers of sulphur had little effect.

Schreiner (61) studied the effect of different salts on oxidation in soil extracts in which wheat seedlings were grown. He reports increased oxidation from the use of calcium sulphate, potassium sulphate, and sodium sulphate.

Dymond, Hughes, and Jupe (18) compared the effect of ammonium sulphate and ammonium chloride on cabbages grown on non-calcareous soil. Greater yields were obtained with the ammonium sulphate than with the ammonium chloride. In their experiments with clover they obtained a 20 per cent increase in hay from the use of gypsum. In pastures they observed that legumes predominated where sulphates were applied, and grasses where no sulphates were used. Gypsum increased the yields of red clover, maize, and vetch in sand cultures, and of vetch in soil cultures. All the pots received applications of calcium and magnesium carbonates.

Lipman and Gericke (40) compared the effects of different nitrogenous fertilizers on barley grown on Oakley's vitro sand, and found the greatest increase with ammonium sulphate. When sulphur containing substances were added to the non-sulphur containing nitrogenous fertilizers, they produced yields equal to those from ammonium sulphate.

SHEDD (63) grew soy beans, oats, alfalfa, and wheat in pots containing Kentucky soils. Eight different soils were used, and flowers of sulphur added at the rate of 100 and 200 pounds per acre. Both controls and sulphur treated pots received tricalcium phosphate, potassium nitrate, and calcium carbonate. There were some increases but also some decreases.

EATON (19) grew sweet corn in pots containing sand. He compared the effect of gypsum, flowers of sulphur, and sodium sulphate. The controls as well as the different sulphur treatments were watered with a nutrient solution which contained no sulphur. Gypsum increased the yield, while flowers of sulphur and sodium sulphate gave increases for the smaller applications and decreases for the larger applications.

DULEY (17) reported a darker green in sweet clover and corn when fertilized with gypsum or sulphur. More nodules were also produced on the roots.

PITZ (57) grew clover in agar-agar containing dipotassium phosphate with and without calcium sulphate. Greater length of roots was obtained with the calcium sulphate. Clover was also grown in Miami silt loam with and without calcium sulphate. The calcium sulphate increased the root length.

HART and TOTTINGHAM (29) found a decided increase in development of beans, red clover, and peas when fertilized with either calcium sulphate or sodium sulphate. In beans and peas the increase was in the seed, in clover it was in the hay and roots. Sulphates increased the yields of both tops and roots in radishes. The yield of rape tops was increased by both calcium and sodium sulphates. Barley was not affected by the sulphates, and oats to only a slight extent.

OLSON (54) conducted field experiments with alfalfa at the Washington Agricultural Experiment Station and obtained increased yields from the use of acid phosphate and gypsum, but not from other forms of phosphorus. Two hundred pounds of gypsum per acre increased the yields of alfalfa from 100 to 500 per cent.

REIMER and TARTAR (58) conducted field experiments on several Oregon soils. Superphosphate, flowers of sulphur, rock phosphate, potassium chloride, potassium sulphate, iron sulphate, gypsum, monocalcium phosphate, sodium nitrate, ammonium sulphate, magnesium sulphate, sodium sulphate, iron pyrites, quick lime, and ground limestone were used as fertilizers. In almost every case enormous increases in yields (from two to ten times as much as the checks) were obtained for all the fertilizers containing sulphur, and no increase or only a small increase for the fertilizers which contained no sulphur. Acid phosphate was compared with gypsum and rock phosphate and with rock phosphate and flowers of sulphur. The yield on the plot receiving rock phosphate and gypsum was considerably greater, and that from the plot receiving rock phosphate and flowers of sulphur slightly greater, than the yield from the acid phosphate treated plot. The alfalfa on all the plots receiving sulphur in any form was a darker green than on the plots which received no sulphur.

Chemical analyses of soil samples from these experimental fields were made. The sulphur content varied from 0.015 to 0.038 per cent in the surface soil, and from 0.014 to 0.030 per cent in the subsoil. The phosphorus content varied from 0.048 to 0.076 per cent in the surface, and from 0.066 to 0.085 per cent in the subsoil. All were high in calcium, magnesium, and potassium.

Investigation

The analyses made by ROBINSON (59, 60) show wide variation in the sulphur content of different soil types. His investigations, although extensive, have included only a part of the numerous soil types found in the United States, so that other soil types should be analyzed to discover their sulphur as well as their phosphorus content. It is also necessary to conduct field experiments on the different soils, as analytical data alone are not sufficient evidence on which to base fertilizer practice. This investigation includes soil analyses and field experiments. Soil samples from Indiana, Kentucky, Michigan, Ohio, and Wisconsin were analyzed for phosphorus, sulphur, and volatile matter (loss on ignition). Field experiments were conducted in Indiana and Kentucky on the fields from which the soil samples were taken.

Soil analysis

METHODS OF SAMPLING.—The soil samples from Michigan and Ohio (nos. 1–9) were taken by Dr. WILLIAM CROCKER and those from Wisconsin (nos. 10–11) by Mr. E. H. HALL. The samples were taken in the usual way by means of a soil auger. The samples from Indiana and Kentucky were taken when the soil was very wet, and as only the surface soil was sampled, it was believed that more accurate sampling could be done by using a spade or shovel. Some soil was removed to a depth of seven inches, leaving one side of the hole vertical, then a thin slice of soil was cut with the spade to the full depth of seven inches. A narrow strip of this extending from top to bottom was removed for the sample. Three or four such samples from different parts of the field were taken and mixed to form a composite sample. The samples from Indiana were taken by JOHN WOODARD, except no. 18, which was taken by Mr. V. G. MANN, and those from Kentucky by JOHN WOODARD, except nos. 32–34, which were taken by Mr. J. C. GENTRY. All the soil samples were air dried, sifted through a 2 mm. sieve, and thoroughly mixed.

ANALYTICAL METHODS.—Phosphorus was determined according to the official magnesium nitrate method of the Official Agricultural Chemists. A blank determination was run to determine the possible presence of phosphorus in the chemicals, but no phosphorus was found.

Sulphur was determined by a modification of the methods of SHEDD and of BROWN and KELLOGG. In preliminary work it was found that higher results were obtained when the iron and aluminum were removed. In soils low in sulphur the barium sulphate precipitated very slowly, so, at the suggestion of Dr. FREDERICK KOCH,[1] 10 cc. of approximately N/10 H_2SO_4 was added immediately before heating the solution and adding the barium chloride. This sulphuric acid was measured in a burette, and exactly the

[1] Unpublished work of Dr. FREDERICK KOCH.

same quantity of the same acid was added to the blank determination, so that subtracting the blank subtracted the sulphur added in the sulphuric acid as well as that present in the reagents. In every case the 10 cc. was measured between the 10 and 20 marks on the burette. According to KOCH, barium sulphate does not precipitate readily when the concentration of the SO_4 ion is low. The addition of the sulphuric acid is then necessary to bring the concentration of the SO_4 ion up to the point where precipitation takes place readily. The method as finally adopted is as follows: The equivalent of 10 gm. of oven dry soil was weighed into a nickel crucible, moistened with a few drops of distilled water, and part of a weighed 20 gm. of sodium peroxide stirred in a little at a time with a nickel rod. (If the moisture was just right, reaction took place immediately without the application of heat, and the charge was fairly dry by the time most of the sodium peroxide had been stirred in. If too little water had been added, it was necessary to heat with an alcohol lamp to start the reaction. If too much water was added, it was necessary to heat with the alcohol lamp to bring to the desired degree of dryness before adding the last of the sodium peroxide.) After the charge was fairly dry, the rest of the sodium peroxide was placed over the charge, the crucible covered, and heated over a bunsen burner, raising the temperature gradually to a fairly high temperature which was maintained for an hour. After cooling, the fused mass was removed with hot distilled water to a 600 cc. beaker, neutralized with concentrated HCl, and then 10 cc. additional concentrated HCl added. The beaker was then heated for five or six hours on the steam bath with occasional stirring. It was then transferred to a 500 cc. flask, covered, and made up to the mark. The solution was shaken frequently for several hours and the 250 cc. filtered off. The 250 cc. of filtrate was transferred to a 600 cc. beaker, heated on the steam bath, and the iron, aluminium, and silica precipitated with ammonium hydroxide, allowed to stand a few minutes, and then filtered into a one liter beaker. The precipitate was washed with hot distilled water until the combined filtrate and washings had a volume of approximately 600 cc. Exactly 10 cc. of approximately N/10 H_2SO_4 was then added, heated to boiling, and 10 cc.

of hot 10 per cent $BaCl_2$ solution added a drop at a time from a pipette. The solution was boiled for ten minutes, placed on the steam bath for two or three hours, and then removed and allowed to stand over night. The barium sulphate precipitate was then filtered off, washed with cold distilled water, transferred to a weighed porcelain crucible, ignited to a dull red in a muffle furnace, cooled in a desiccator, and weighed. Blanks were determined using the same reagents and adding the same quality of the same sulphuric acid that was used in the determination.

The loss on ignition was determined on samples which had been used for determining moisture. The moisture was determined by heating 10 gm. of air dry soil in the oven for five or six hours. Part of the samples were heated to 100° C. in an ordinary oven and part of them to 35° C. in a vacuum oven. After weighing for the moisture determination, the sample was placed in the muffle furnace, heated to a dull red for an hour, cooled in a desiccator, and weighed. The loss on ignition was calculated as percentage of oven dry soil. Table I gives the results of the analytical work on all the soils analyzed. Phosphorus, sulphur, and volatile matter (loss on ignition) are reported as percentage of oven dry soil.

Sulphur is present in the soil either in the form of sulphates of calcium, magnesium, and iron, or in the form of organic matter. All the sulphates are quite soluble and are not readily adsorbed, so that they are leached out rapidly and only small amounts are present in the soil. On the other hand, the organic sulphur is insoluble and remains in the soil until oxidized to sulphates. One would expect, therefore, some sort of relation between the sulphur content of the soil and the volatile matter (loss on ignition), which is a rough method of determining the organic matter. The data in table I, however, indicate only a general relation, and that only when samples from the same soil type or closely related soil types are compared. The soil samples from Wisconsin are from the same soil type, but differ in amount of organic matter. There is also a difference in content of sulphur, and the higher sulphur content is found in the sample with the higher content of organic matter. This is true for both surface soil and subsoil. The Michigan

TABLE I

Sample no.	Soil strata (inches)	Name of farm or farm owner	Location	Percentage of volatile matter	Percentage of sulphur	Percentage of phosphorus
1 A...	0–6	Wah-Bee-Mee-Mee farm	Michigan	2.076	0.0158	0.0360
1 B...	7–14	Wah-Bee-Mee-Mee farm	Michigan	2.341	0.0157	0.0330
1 C...	15–24	Wah-Bee-Mee-Mee farm	Michigan	2.662	0.0216	0.0305
2 A...	0–6	Wah-Bee-Mee-Mee farm	Michigan	4.988	0.0486	0.0518
2 B...	7–14	Wah-Bee-Mee-Mee farm	Michigan	4.481	0.0405	0.0561
3 A...	0–6	Wah-Bee-Mee-Mee farm	Michigan	2.863	0.0183	0.0390
3 B...	7–14	Wah-Bee-Mee-Mee farm	Michigan	2.522	0.0159	0.0324
4 A...	0–6	Wah-Bee-Mee-Mee farm	Michigan	4.862	0.0361	Not determined
4 B...	7–14	Wah-Bee-Mee-Mee farm	Michigan	3.754	0.0263	Not determined
5 A...	0–6	Wah-Bee-Mee-Mee farm	Michigan	4.311	0.0319	0.0514
5 B...	7–14	Wah-Bee-Mee-Mee farm	Michigan	3.822	0.0283	0.0468
5 C...	15–24	Wah-Bee-Mee-Mee farm	Michigan	3.462	0.0177	0.0305
6 A...	0–6	Everett's farm	Ohio	3.631	0.0232	0.0788
6 B...	7–14	Everett's farm	Ohio	2.466	0.0140	0.0411
7 A...	0–6	Arnold's farm	Ohio	4.642	0.0334	0.0771
7 B...	7–	Arnold's farm	Ohio	2.984	0.0195	0.0423
8 A...	0–6	Jacoby's farm	Ohio	5.228	0.0281	0.0582
8 B...	7–	Jacoby's farm	Ohio	3.148	0.0050	0.0326
9 A...	0–6	Jacoby's farm	Ohio	14.327	0.0905	0.0939
9 B...	7–	Jacoby's farm	Ohio	5.969	0.0194	0.0343
10 A...	0–6	Wager's farm	Wisconsin	8.116	0.0351	0.0744
10 B...	7–	Wager's farm	Wisconsin	6.954	0.0202	0.0649
11 A...	0–6	Wager's farm	Wisconsin	6.836	0.0245	0.0795
11 B...	7–	Wager's farm	Wisconsin	4.043	0.0124	0.0457
12.....	0–6	Ross's farm	Indiana	5.758	0.0172	0.1054
13.....	0–6	Carr's farm	Indiana	4.721	0.0165	0.0628
14.....	0–6	Reich's farm	Indiana	4.075	0.0118	0.0490
15.....	0–6	Bentley's farm (cropped soil)	Indiana	4.809	0.0155	0.0566
16.....	0–6	Bentley's farm (virgin soil)	Indiana	5.249	0.0233	0.0564
17.....	0–6	Barnett's farm	Indiana	4.462	0.0183	0.0492
18.....	0–6	McCulloch's farm	Indiana	4.807	0.0155	0.0578
19.....	0–6	Adina farm	Kentucky	7.024	0.0258	0.1897
20.....	0–6	Adina farm	Kentucky	4.526	0.0232	0.0799
21.....	0–6	Adina farm	Kentucky	7.496	0.0131	0.1636
22.....	0–6	Adina farm	Kentucky	4.884	0.0122	0.1298
23.....	0–6	Adina farm	Kentucky	4.318	0.0206	0.0768
24.....	0–6	Marshall's farm	Kentucky	5.517	0.0264	0.1377
25.....	0–6	Downing's farm	Kentucky	5.466	0.0159	0.0977
26.....	0–6	Downing's farm	Kentucky	5.229	0.0236	0.1765
27.....	0–6	Downing's farm	Kentucky	5.327	0.0153	0.1370
28.....	0–6	Gentry and Curry's farm	Kentucky	6.021	0.0245	0.2355
29.....	0–6	Scott's farm	Kentucky	5.088	0.0235	0.1500
30.....	0–6	Sharp's farm	Kentucky	6.540	0.0161	0.1779
31.....	0–6	Moore's farm	Kentucky	4.723	0.0253	0.1007
32.....	0–6	Fowler's farm	Kentucky	5.051	0.0250	0.1727
33.....	0–6	Watt's farm	Kentucky	5.836	0.0163	0.1306
34.....	0–6	Tuomey's farm	Kentucky	11.105	0.0313	0.3407

soil samples are also quite similar in texture. Here again we find a high sulphur content with a high organic matter content, and a low sulphur content with a low organic matter content. When we compare different soil types or samples from the same type but from fields which have been cropped differently, however, there is little evidence of any relation. Samples 7 B and 9 B have approximately the same sulphur content, yet the volatile matter in the latter is twice that in the former. Both these samples are subsoils from Ohio, and were taken from fields that were not far apart, but 7 B is on upland silt loam while 9 B is a muck soil. Again, the cropped soil (no. 15) and the virgin soil (no. 16) from Bentley's farm, Indiana, differ only slightly in volatile matter, but differ widely in sulphur content. Gentry and Curry's soil (no. 28) has slightly less volatile matter than Sharp's soil (no. 30), but considerably more sulphur. Sample 10 A from Wager's farm in Wisconsin is a fine sandy loam soil with very little clay but a large amount of organic matter, as may be recognized by its black color, yet it contains considerably less sulphur than sample 2 A from the Wah-Bee-Mee-Mee farm in Michigan, which is also a sandy loam soil, containing considerable coarse sand with sufficient organic matter to give a black color.

It seems, then, that from the sulphur standpoint, as well as the nitrogen standpoint, the character of the organic matter is of more importance than the amount. Sulphur, like nitrogen, is mainly present in the proteins, so that a small amount of high protein organic matter, such as one would obtain by plowing under legumes, would be more valuable than a larger quantity of organic matter from wheat or oat straw or cornstalks. It seems probable also that the proteins are more readily decomposed than the non-protein organic matter, so that the sulphur and nitrogen would be oxidized more rapidly than the carbon, and the sulphur and nitrogen content might become quite low when there was still a considerable amount of carbonaceous organic matter in the soil.

In all the samples analyzed, the sulphur content was less than the phosphorus content. One of the samples from Ohio which was taken in a low wet place was a muck, very high in organic matter. This soil had nearly as much sulphur as phosphorus in the surface soil (no. 9 A), but the subsoil (no. 9 B) had only a little more than half as much sulphur as phosphorus. The difference between the sulphur and phosphorus contents in one of the Michigan soils was not great. The surface soil (no. 2 A) contained 0.0486 per cent sulphur and 0.0518 per cent phosphorus, while the subsoil (no. 2 B) contained 0.0405 per cent sulphur and 0.0561 per cent phosphorus. All the other samples were much higher in phosphorus than in sulphur. The difference was very great in one of the Indiana soils, which had over six times as much phosphorus as sulphur, and in the Kentucky soils, in most of which the phosphorus content was from five to eleven times as much as the sulphur. In two of the Kentucky soils the phosphorus content was only three times as much as the sulphur, and in one only four times as much.

The Michigan soils, samples 1–5, were taken on the Wah-Bee-Mee-Mee farm at White Pigeon, Michigan. Samples 1 and 5 were sampled to three depths and all the others to two depths. These soils are alluvial sandy loams, varying from light brown to dark brown on the surface and grading into a yellow sandy subsoil containing some gravel. The light colored samples contained more sand in both surface and subsoil and were lower in volatile matter, sulphur, and phosphorus, than the darker colored ones. All were low in both sulphur and phosphorus, but the sulphur is lower than phosphorus in all the samples. With the exception of sample 1, the sulphur was always lower in the subsoil than in the surface soil.

The Ohio soils, samples 6–9, were taken near Copley, Ohio. Nos. 6, 7, and 8 are upland silt loams containing some sand. The surface soil is a yellow brown grading into a uniformly light yellow subsoil, which indicates good underdrainage as well as good surface drainage. These soils apparently belong to the type mapped as the Wooster silt loam. The sulphur content was low in both surface and subsoil, while the phosphorus content was fairly good in the surface but low in the subsoil. In every sample the subsoil was lower in volatile matter, sulphur, and phosphorus than the corresponding surface soil.

Sample 9 is poorly drained, and the surface soil has a large amount of organic matter with some silt, sand, and a little clay.

The subsoil has much less organic matter, but the proportion of its other constituents is about the same as in the surface. The surface soil is very high in volatile matter, sulphur, and phosphorus, while the subsoil is very low in both sulphur and phosphorus.

The Wisconsin soils, samples 10 and 11, are from near Beloit, Wisconsin. They are fine sandy loams, dark brown on the surface and a lighter brown in the subsoil. In both samples the volatile matter, sulphur, and phosphorus are higher in the surface soil than in the subsoil. The sulphur content is low in both surface soil and subsoil in both samples, but the phosphorus is good in the surface soil of both samples, fair in the subsoil of sample 10, and poor in the subsoil of sample 11. Both sulphur and phosphorus are lower in the subsoil than the surface soil in both samples.

The Indiana soil samples (nos. 12–18) were taken near Charlestown, Clark County, Indiana. This region is underlain by limestone rock, but the rock has been covered by a thick layer of windblown material, from which most of the soils were formed. All the soils sampled were formed from this windblown material except no. 12, which was taken on the bluff of a small stream where there was considerable erosion. It seems that the erosion has removed the greater part of the windblown material, and to a large extent the soil is formed from the underlying limestone. This is probably the reason why this sample resembles in general appearance and in chemical composition the Kentucky soils rather than the adjacent soils from the windblown material or loess. Sample 12 has a light brown silt loam surface soil grading into a reddish yellow subsoil. Like the other Indiana soils, the volatile matter and sulphur are low, but the phosphorus is high like most of the Kentucky soils.

The loessal soils include two types, the one with good natural underdrainage and the other with poor drainage. The former, which includes samples 15–18, is a yellow gray silt loam in the surface soil and a yellow silt loam in the subsoil. The latter, which includes samples 13 and 14, has a gray or slightly yellowish gray silt loam surface soil underlain by a gray or gray and yellow mottled silt loam subsoil. Both are poorly drained, but sample 13 is more nearly level and has more gray color in both surface and subsoil. All the samples from both types are low in volatile matter, sulphur, and phosphorus. Samples 15 and 16 were taken a few rods apart, the former from a field which had been in alfalfa for several years, and the latter from virgin land. Both have practically the same phosphorus content, but the sulphur is much higher in the virgin soil.

All the soil samples from Kentucky (nos. 19–34) are residual limestone soils, but no. 34 was derived from the Trenton limestone, which is high in phosphorus, while the others are all from the Cincinnati limestone, but no. 28 was taken from soil derived from Cincinnati limestone, but it was only a short distance from the division line between the Cincinnati and Trenton formations, and had probably received some material from the Trenton formation. Samples 19–27 are from Mason County, while samples 28–34 are from Mercer County. Samples 19 and 21 are clay loams, while 20 and 22–27 are silt loams. All are light brown to grayish brown in color. Sample 34 is a heavy clay loam, sample 28 is a heavy silt loam or light clay loam, while samples 29–33 are silt loams. Samples 31 and 33 are quite gray in color, and 33 contains iron concretions. No. 31 is known locally as white oak land, and both are recognized as poor soils. All the other samples are light brown except no. 34, which is a grayish brown. All the Kentucky soils are low in volatile matter except the clay loams, in which part of the volatile matter is probably water of combination. All are low in sulphur, no. 34 being the only one above 0.03 per cent. This sample is from the Trenton formation and contains many unweathered fragments of limestone. It is possible that the sulphur content as well as the phosphorus content of the Trenton limestone may be higher than in other formations. No. 34 contains 0.3407 per cent of phosphorus, which is eleven times as great as the sulphur content. This is much higher than any of the others, but all the others are high in phosphorus.

RELATION BETWEEN AMOUNTS OF SULPHUR AND PHOSPHORUS REMOVED BY CROPS AND SULPHUR AND PHOSPHORUS CONTENTS OF SOILS.—A better idea of the supply of sulphur and phosphorus in the soil can be obtained if the pounds per acre of these elements found in the surface soil is compared with the amounts removed by some of our common crops. Table II gives the amounts of sulphur and phosphorus removed by some of the common crops. The yields per acre and the amounts of phosphorus removed by these yields are taken from HOPKINS and PETTIT'S (34) table, while the amounts of sulphur removed are computed from HART and PETERSON'S analyses.

As pointed out by HOPKINS and PETTIT (34), these yields are exceptionally large, but they have been obtained by some farmers, and others may obtain them under proper systems of farming. If, however, smaller yields are removed, it will not prevent soil depletion, but will only delay soil exhaustion if the elements removed

TABLE II

POUNDS PER ACRE REMOVED BY FARM CROPS

Crop	Yield per acre	Pounds per acre removed annually	
		Sulphur	Phosphorus
Corn, grain	100 bushels	7.8	17.0
Oats, grain	100 bushels	5.8	11.0
Wheat, grain	50 bushels	5.1	12.0
Timothy, hay	3 tons	11.4	9.0
Clover, hay	4 tons	13.0	20.0
Alfalfa, hay	8 tons	46.0	36.0
Potatoes	300 bushels	24.7	13.0

are not returned in some form. In actual practice, failure to return to the soil the elements of plant food which are removed in the crops will result in a gradual decrease in yields, so that the amounts of plant food removed will gradually become less. It is impossible to determine the time when complete exhaustion will take place, but a comparison of the amounts of plant food removed by large crops with the amounts present in the soil will emphasize the importance of renewing the supply in the soil before the soil supply is reduced below that necessary for satisfactory crop yields. Table III gives the pounds per acre of sulphur and phosphorus in the surface soils analyzed and the number of years' supply of each for several common farm crops, if maximum crops are removed, such as are given in table II.

Table III shows that all the soils are too low in sulphur to grow alfalfa for 40 years, while 22 of them have phosphorus enough to grow alfalfa 40 years or longer, provided, of course, none of these elements is added in any way and none removed except in the crops. Sample 9A, which has the highest sulphur content, has sulphur

TABLE III

POUNDS PER ACRE OF SULPHUR AND PHOSPHORUS AND NUMBER OF YEARS' SUPPLY FOR VARIOUS CROPS IF MAXIMUM CROPS ARE REMOVED

Soil no.	Sulphur						Phosphorus					
	Pounds per acre in soil	No. of years' supply for					Pounds per acre in soil	No. of years' supply for				
		Corn	Wheat	Timothy	Clover	Alfalfa		Corn	Wheat	Timothy	Clover	Alfalfa
1 A	316	40	62	28	24	7	720	42	60	80	36	20
2 A	972	125	191	85	75	21	1036	61	86	115	52	29
3 A	366	47	72	30	28	8	780	46	63	83	39	22
4 A	722	93	142	63	56	16	.....	.....	.....	.....	.....	.....
5 A	638	82	125	56	49	14	1028	60	86	114	51	29
6 A	464	60	91	41	36	10	1576	93	131	175	79	44
7 A	668	86	131	60	51	14	1542	91	129	171	77	43
8 A	562	72	110	50	43	12	1164	68	97	129	58	32
9 A	1810	232	355	159	139	39	1878	110	156	209	94	52
10 A	702	90	138	62	54	15	1488	88	124	165	74	41
11 A	490	63	96	43	38	11	1590	94	133	177	80	44
12	344	44	67	30	26	7	2108	124	176	234	105	59
13	330	42	65	29	25	7	1256	74	105	139	63	35
14	236	30	46	21	18	5	980	58	82	109	49	27
15	310	40	61	28	24	7	1132	67	94	126	57	31
16	466	60	91	41	36	10	1128	66	94	125	56	31
17	366	47	72	32	28	8	984	58	82	109	49	27
18	310	40	61	28	24	7	1156	68	96	128	58	32
19	516	66	101	45	40	11	3794	223	316	422	190	105
20	464	60	91	41	36	10	1598	94	133	177	80	44
21	262	34	51	23	20	6	3272	192	273	364	164	91
22	244	31	48	22	19	5	2596	153	216	288	130	72
23	412	53	88	36	32	9	1536	90	128	171	77	43
24	528	68	104	46	41	11	2754	162	230	306	138	77
25	318	41	64	28	24	7	1954	115	163	216	98	54
26	472	61	93	41	36	10	3530	208	294	392	177	98
27	306	39	50	27	24	7	2740	161	228	304	137	76
28	490	63	96	43	38	11	4710	277	393	523	236	131
29	470	60	92	41	36	10	3000	176	250	333	150	83
30	322	41	63	28	25	7	3558	209	296	395	178	99
31	506	65	99	44	39	11	2014	118	168	224	101	56
32	500	64	98	44	38	11	3454	203	288	384	173	96
33	326	42	64	29	25	7	2612	154	218	290	131	73
34	626	80	122	55	48	14	6814	401	568	757	341	189

enough for 39 years of alfalfa and phosphorus enough for 52 years of alfalfa. Only one other soil, no. 2 A, had enough sulphur for 20 years of alfalfa, while three soils, nos. 19, 28, and 34, have enough phosphorus for 100 or more years of alfalfa. No. 34 has phosphorus enough to grow alfalfa 189 years, but sulphur enough for only 14 years. The phosphorus content of no. 28 is sufficient to grow alfalfa for 131 years, but the same crop would deplete the sulphur in 11 years. All these soils have sufficient phosphorus to grow maximum yields of alfalfa for 20 years or longer, while all but two would be depleted of sulphur in less than 20 years.

Of the other crops mentioned, corn, wheat, and clover remove smaller amounts of sulphur than phosphorus; while timothy, like alfalfa, removes more sulphur than phosphorus. Timothy, however, removes only about one-fourth as much sulphur, and one-fourth as much phosphorus as alfalfa, so that the supply of each would last correspondingly longer, yet soil 9A is the only one that carries sufficient sulphur for 100 crops of timothy. Soil 9A has sulphur enough to grow timothy 159 years, clover 139 years, corn 232 years, and wheat 355 years. No. 34 has phosphorus enough for 401 corn crops, 568 wheat crops, and 341 clover crops; yet the sulphur would be depleted by 80 corn crops, 122 wheat crops, or 48 clover crops. The lowest phosphorus content is in soil 1A, a sandy loam soil, which has 720 pounds of phosphorus in the surface 7 inches of soil. The phosphorus in this soil would be depleted by growing corn 42 years, wheat 60 years, timothy 80 years, clover 36 years, or alfalfa 20 years. In the same soil the sulphur would be removed by 40 years of corn, 62 of wheat, 28 of timothy, 24 of clover, or 7 of alfalfa.

Table III shows the importance of both sulphur and phosphorus if maximum crops of legumes, particularly alfalfa, are to be grown. It also shows that, in most soils, sulphur is more likely to be deficient than phosphorus. It does not take into account the leaching of these elements from the soil, which is practically nil in the case of phosphorus and very high in the case of sulphur; nor the supply in the rain water, which is nil in the case of phosphorus and may be quite high in the case of sulphur near cities in the humid regions. Whether the amount of sulphur lost in the drainage water exceeds that gained in the rain water is still unknown. It is certain that the amount of leaching will vary with the character of the soil, the rainfall, and the character of the plant growth. The amount of sulphur in the rain water will vary with the rainfall and the nearness to cities where large amounts of soft coal are used. It is possible that, in some places under certain conditions, the amount of sulphur brought down in the rain water will equal or exceed that lost in the drainage, but that in other places and under other conditions the loss will exceed the gain. Field experiments are needed to see whether the plants will respond to sulphur fertilization under field conditions. Remarkable responses were obtained by JUDGE PETERS, JOHN BINNS, and EDMUND RUFFIN in the Eastern United States (CROCKER, 15), and have recently been obtained on the Pacific Coast by REIMER and TARTAR (58) in Oregon, and by OLSON (54) in Washington. To secure further information along this line, cooperative experiments were conducted on some farms in Indiana and Kentucky from which some of the samples reported in table I were taken.

COOPERATIVE FIELD EXPERIMENTS WITH GYPSUM

The field experiments were conducted in cooperation with the farm owners. The farm owners were to apply gypsum and report on the effect on yields, if any. Some of the farmers failed to make any report, and those who did gave no weights, so that the results are not as satisfactory as could be desired. Results reported are as follows.

In the Indiana experiments, gypsum was applied to alfalfa, red clover, and tobacco. The only report received was with regard to the tobacco. This tobacco field was on the farm of Mr. ROSS, southwest of Charlestown, Indiana. This is the field from which sample 12 was taken, and, as shown in tables I and III, is low in sulphur and high in phosphorus. Mr. ROSS reports a marked increase in yield of tobacco from the use of gypsum on this field, but gives no quantitative data.

Gypsum was applied to alfalfa, red clover, sweet clover, and tobacco in Mason County, Kentucky. The crops were injured so badly by weather conditions, however, that no results were obtained.

In Mercer County, Kentucky, gypsum was applied to tobacco, clover, and alfalfa. Of the farmers responding, Mr. SHARP reported no increase in tobacco, while Mr. FOWLER reported an increase in the second clover crop, and Mr. TUOMEY an increase in alfalfa. Neither of these men weighed the hay, so the results are not quantitative. Mr. SHARP's field, from which sample 30 was taken, is low in sulphur and high in phosphorus, but it showed evidences of being farmed hard, and was evidently low in nitrogen, which was probably the limiting element for a non-leguminous crop like tobacco. Mr. FOWLER's soil, no. 32, has 0.0250 per cent sulphur and 0.1727 per cent phosphorus, equivalent to 500 pounds of sulphur, and 3454 pounds of phosphorus, in the surface soil; so sulphur was probably the limiting element for clover. Mr. TUOMEY's field, sample 34, had 6814 pounds of phosphorus, the highest of the samples analyzed. This sample also contained small fragments of limestone, so that there was an abundance of lime. On the other hand, the sulphur content, 626 pounds, although higher than in many samples, is probably rather low for a plant like alfalfa, which uses such large quantities of sulphur.

These results are not conclusive, but it seems probable that sulphur may be a limiting element on some of these soils, and that gypsum is a satisfactory source of supply for this element. More field experiments are necessary in the humid part of the United States, and great care in conducting these experiments is necessary if satisfactory results are to be obtained. Experiments should be conducted through several years to avoid weather conditions, which may be the limiting factor in some years. On some soils drainage is necessary, and no fertilizer treatment will have any effect until this is done. Most soils in the humid part of the United States are acid. A large part of them are so acid that liming is necessary before any other treatment is effective, especially for leguminous crops. Table I shows a high phosphorus content in some of the soils reported in this paper, but those are exceptional soils. As a general rule soils are deficient in phosphorus, and farmers report increases in crop yields for the use of acid phosphate. It is impossible, however, to tell how much of the increase is due to the phosphorus and how much to the sulphur in the acid phosphate. A comparison of acid phosphate with rock phosphate and gypsum, and with gypsum alone, and rock phosphate alone would give some valuable results.

Many of the Illinois experiment fields include three check plots in each series. These check plots are all untreated and are only a short distance apart, yet some of them differ widely in crop yields. It is reasonable to assume that neighboring plots receiving the same fertilizer treatment would differ as widely. These differences due to factors not under the control of the investigators make the probable error large, and when only one plot of each treatment is used, the differences between plots with different treatments must be great before one can assume that the treatment has been effective. Where the differences are as great as in the work of REIMER and TARTAR (58) and of OLSON (54), there is no doubt that the treatment has been effective, but in many of the field experiments in different parts of the country the differences are too small to justify the conclusions drawn from them, as the probable error is so great. Where a number of plots of each treatment are used, the uncontrollable factors tend to neutralize each other and the probable error is reduced. As the number of plots of each treatment increases, smaller average differences are necessary to be significant. It seems probable that three plots of each treatment are necessary if satisfactory results are to be obtained. In the past investigators have had a tendency to scatter field experiments over a number of widely separated fields on the same soil type. It seems probable that more satisfactory results would be obtained if the work were confined to one field on each soil type, and each field had from three to five plots of each treatment.

Summary

1. Composite soil samples from Indiana, Kentucky, Michigan, Ohio, and Wisconsin were analyzed for total sulphur, total phosphorus, and volatile matter (loss on ignition), and cooperative fertilizer experiments with gypsum were conducted in fields in Indiana and Kentucky.

2. The analytical data show a general relation between the sulphur content and loss on ignition in soil samples from the same soil type or closely related soil types, but the relation is not apparent when different soil types are compared.

3. The sulphur contents in the surface soil vary from 0.0118 to 0.0905 per cent, while the phosphorus contents vary from 0.0360 to 0.3407 per cent. All the upland soils and most of the alluvial soils are low in sulphur. Most of the Kentucky soils and one of the Indiana soils are high in phosphorus. This is undoubtedly due to the influence of the rock from which the soils were formed, as all the Kentucky samples were from soils derived either from the Trenton limestone or the Cincinnati limestone, both of which are high in phosphorus content.

4. The sulphur and phosphorus contents were calculated to pounds per acre in the surface soil, and compared with the amounts of sulphur and phosphorus removed by maximum crops of corn, wheat, timothy, clover, and alfalfa. The highest sulphur content is sufficient for only 39 years of alfalfa, 139 of clover, 159 of timothy, 355 of wheat, or 232 of corn; while the lowest sulphur content is sufficient for only 5 years of alfalfa, 18 of clover, 21 of timothy, 46 of wheat, or 30 of corn. The lowest phosphorus content is equal to the amount removed by 42 years of corn, 60 of wheat, 80 of timothy, 36 of clover, or 20 of alfalfa. On the other hand, it would take 401 years of corn, 568 of wheat, 757 of timothy, 341 of clover, or 189 of alfalfa to remove as much phosphorus as is found in the soil with the highest phosphorus content.

5. On some of the soils tobacco, clover, and alfalfa have been benefited by the use of gypsum. The results, however, are not quantitative. More field experiments are needed and greater care should be taken to eliminate other factors as far as possible. Each treatment should be replicated to reduce the probable error.

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